

RELATION OF THE TIME INTERVAL TO ACCURACY OF DOUBLE THEODOLITE OBSERVATIONS

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ABSTRACT

Low-level wind observations were made by manual theodolite readings of pilot balloon positions. Simultaneous readings were made from three theodolites with time intervals ranging from 5 to 60 sec. and for altitudes up to 8,428 ft. above the surface. The theodolite readings were analyzed as three simultaneous double theodolite observations of the wind vectors between the successively observed positions of the balloons. If the theodolite readings were completely accurate, each of the three simultaneous wind vectors would be identical. The differences between the magnitudes and directions of the horizontal components of the simultaneous wind vectors were used as a measure of the observational accuracy of the balloon movements. Twenty-sec. intervals between theodolite readings were found to give the greatest accuracy; the accuracy decreased rapidly as the time interval was shortened but the accuracy was nearly the same as the time interval was increased.

1. INTRODUCTION

The simultaneous observation of a balloon from two theodolites is one of the most accurate methods of measuring low-level wind conditions. When especially detailed wind observations are wanted, the time interval between successive readings of the balloon position is shortened. As this interval becomes shorter there should be a minimum time interval below which the accuracy of the wind observations deteriorates rapidly. The purpose of this investigation is to examine the accuracy of double theodolite observations as the time interval is decreased.

2. APPROACH

The problem of using balloons to obtain accurate observations of wind conditions could be broken into at least three parts. First, the successive positions of the balloons must be observed accurately; second, it is assumed that a balloon accurately follows the flow of air particles; third, it is assumed that the air flow shown by the balloon is the same as the air flow at slightly different times and locations. This report treats only the first part.

Five series of simultaneous observations from three theodolites were made at the U.S. Army Proving Ground, Yuma, Ariz., in May 1964 by a combined group of experienced U.S. Army and U.S. Weather Bureau meteorological observers. The three theodolite sites (A, B, C) approximated an isosceles triangle with two sides 1,000 m. long

and the other 1,414 m. long. The altitudes of the sites were 329, 394, and 426 ft. m.s.l., respectively. Observations were made using standard U.S. Army Signal Corps Theodolites, Models ML-247 and ML-474 GM. Five sequences of pilot balloon observations were made with three theodolites on each of five different days. (25 balloons were released.) On each day, one sequence was made with a 5-sec. interval between readings, one with a 10-sec. interval, one with a 20-sec. interval, one with a 30-sec. interval, and one with a 60-sec. interval. Each theodolite had two observers, and a seventh observer was used to coordinate the timing of observations. The azimuth and elevation angles were read to $\frac{1}{10}$ th of a degree. The maximum heights of the balloons while observed ranged from 1,870 ft. to 4,928 ft. above the surface.

The data were divided into three sets of double theodolite readings: theodolites A and B, B and C, and A and C. Simultaneous azimuth angle readings were used to calculate (on a G-15 computer) the horizontal projection of the balloon path between two successive readings. This resulted in three wind vectors to represent the wind experienced by the balloon between each two successive readings. If perfect observational accuracy had been attained, the three wind vectors for each wind condition would be identical in magnitude (m.p.h.) and in direction (degrees azimuth).

For each of three wind vectors, the magnitude of the smallest was divided by the magnitude of the largest to obtain the "apparent horizontal wind speed ratio." A ratio of 100 percent could be attained only when all three vectors were of exactly the same magnitude. As the

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differences between vector magnitudes increased, the ratio decreased.

Likewise, for each set of three wind vectors, the maximum difference in directions (degrees azimuth) between any two vectors was called the "apparent horizontal wind direction departure." This was tabulated in degrees. In this case, a smaller number indicates greater accuracy.

Several steps were taken to insure the validity of the results. The five observations for the first day were not used even though all observers were experienced. This was to insure that each observer had some familiarity with reading the instrument at the different time intervals. The order of the different reading time intervals was different each day to minimize the influence of observer fatigue or of diurnal wind changes. To eliminate the mathematical uncertainty of finding the intersection point of two nearly coincident lines, all sets of data for any one reading were discarded if any azimuth angle was within 5° of a base line to another theodolite. To exclude cases in which a very slight difference between two wind vectors would give an unreasonably adverse "wind speed ratio," data were discarded for wind speeds less than 3 m.p.h. Finally, a larger number of short time interval readings was made so all balloons traversed approximately the same positions relative to the theodolites; this minimized geometric errors. See [1] for a comprehensive analysis of geometric factors.

For each time interval, the means were found for the "apparent horizontal wind speed ratio," and for the "apparent horizontal wind direction departure." The results are shown in figure 1. Note that a time interval of 20 sec. gives a ratio of 95.2 percent and a departure of 1.4° ; these were the best accuracies found. A total of 119 triple theodolite or 357 double theodolite readings was used.

3. DISCUSSION

This analysis shows that the 20-sec. reading interval was the most accurate but was only slightly more accurate than either the 30- or the 60-sec. interval. This may reflect an insufficient number of observations to attain statistical significance, but the parallelism of the speed and direction mean data tends to eliminate this conclusion.

The accuracy maximum at 20-sec. reading intervals seemed so remarkable that a second series of triple theodolite observations was made in the same area near Yuma during August 1964 using 15-, 20-, 30-, and 45-sec. reading time intervals. About half of the observers had participated in the first series of observations. The data were analyzed in the same manner with the results shown in figure 2. Again an optimum time interval of 20 sec. was found with a ratio of 93.7 percent and a departure of 4.16° . (The over-all decrease in accuracy may have been a result of the more intense heat during August.) The maximum heights of the balloons while observed ranged from 3,917 ft. to 8,428 ft. above the surface. A total of 64 triple theodolite or 192 double theodolite readings was used.

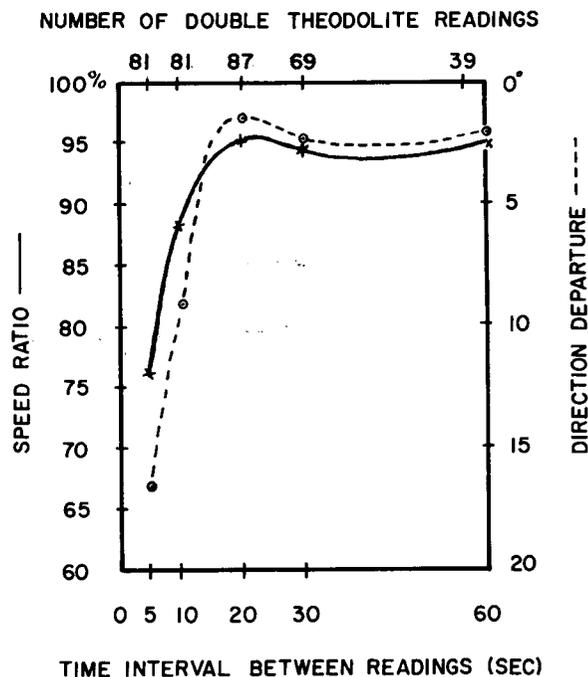


FIGURE 1.—Results of first test. Apparent horizontal wind speed ratio (solid line) and apparent horizontal wind direction departure (broken line) as functions of time interval between readings by double theodolites.

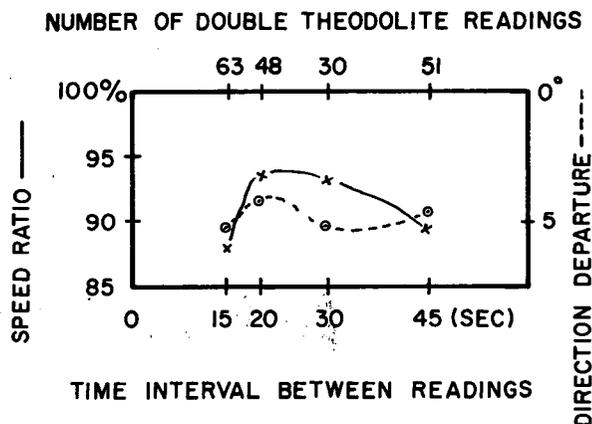


FIGURE 2.—Results of second test. Apparent horizontal wind speed ratio (solid line) and apparent horizontal wind direction departure (broken line) as functions of time interval between readings by double theodolites.

Since the experiment was "randomized," it appears that the possibility that the 20-sec. interval readings could have been taken under consistently more favorable geometric, wind, or atmospheric refraction conditions was greatly minimized.

If the varying lengths of the runs were a significant factor, there should be a more nearly linear variation between the 5-sec. and the 60-sec. cases. As figures 1 and 2 indicate, this is not the case; the curves are peaked at 20 sec. in both figures.

Since only azimuth readings were used in the analyses there should be no contributing error due to differences in the elevation of observing sites. A negligible error is due to the earth's curvature but this would not favor a 20-sec. reading interval.

There is the possibility that the 20-sec. interval is the minimum time required for the average observer to center the balloon on the cross-hairs for each successive reading. Less time may not be sufficient for this and more time may permit the observer time enough to become distracted thereby causing a late reading or a reading in which the tracking instrument is not exactly on target.

4. SUMMARY AND CONCLUSIONS

Analyses were made of 549 double theodolite readings with reading intervals of 5, 10, 15, 20, 30, 45, and 60 sec. to determine which reading interval gives the most accurate observations of successive balloon positions.

The data indicate that for double theodolite runs of

short duration and using skilled observers, the time interval of 20 sec. between readings provided the most accurate determination of horizontal winds of the lower atmosphere. Accuracy decreased rapidly as time intervals were made less than 20 sec. For time intervals greater than 20 sec., accuracy was slightly less.

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